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RESEARCH MEMORANDUM

APPRAISAL OF THE HAZARDS OF FRICTION-SPARK IGNITION OF AIRCRAFT CRASH FIRES

By John A. Campbell

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RESEARCH MEMORANDUM

APPRAISAL OF THE HAZARDS OF FRICTION-SPARK IGNITION OF AIRCRAFT CRASH FIRES

By John A. Campbell

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SUMMARY

A study was made to determine if common aircraft metals produce friction sparks capable of igniting combustibles that might be spilled in an airplane crash. Samples of aluminum, titanium, magnesium, chrome-molybdenum steel, and stainless steel were dragged over both concrete and asphalt runways while a combustible mixture of gasoline, JP-4 fuel, kerosene, or preheated oil was sprayed around the sample.

No ignitions occurred from sliding aluminum at bearing pressures up to 1455 pounds per square inch and slide speeds up to 40 miles per hour. From a study of these results and of related literature, it is believed that aluminum would not be an ignition source even at higher bearing pressures and slide speeds. Titanium, magnesium, chrome-molybdenum steel, and stainless steel produced friction sparks that ignited the combustibles at sliding speeds and bearing pressures well below those that could be expected in a crash.

INTRODUCTION

Hot or burning metal particles, commonly known as friction sparks, abraded from an aircraft structure during a crash may contact spilled combustibles and start a fire. It is known from experimental crashes (ref. 1) that abraded steel particles can ignite spilled gasoline. In these experimental crashes, steel and aluminum were the only metals studied; and no fires resulted from abraded aluminum particles. Since only steel and aluminum had been studied, it was desirable to expand the investigation to cover other aircraft metals and other combustibles. The purpose of the present study, therefore, was to determine which aircraft metals sliding over a runway would ignite spilled combustibles by friction sparks and the slide speeds and bearing pressures under which ignition would occur.

The probability that a friction spark will ignite a combustible fuel-air mixture depends on the character of the fuel and the thermal energy of the spark. The thermal energy in a friction spark depends largely on the energy put into the metal, the hardness of the metal, and the temperature at which particles of the metal burn. The energy put into the metal, and thus the thermal energy of the friction spark, will increase with increased bearing pressure and increased slide speed. The greater the hardness of the metal, the greater the energy required to abrade particles from the metal. If the metal particles reach their ignition temperature in being abraded, they will burn. This oxidation then further increases the thermal energy available for igniting combustible mixtures. Although the presence of luminous metal particles indicates that they are burning (ref. 2), it does not necessarily indicate that combustibles, such as gasoline, will be ignited. The size and temperature of the particles must be such that sufficient thermal energy can be transmitted to the combustible to raise it to its ignition temperature (ref. 3).

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The surfaces of the parent metal or metal smeared on to the runway may also be hot enough to ignite combustible fuel-air mixtures. This possibility was studied only when the friction sparks did not act as an ignition source.

This study of friction-spark ignition was conducted by dragging a sample of typical aircraft metal over both concrete and asphalt runways at various speeds and bearing pressures while the sample was surrounded with a combustible fuel-air mixture. (The term concrete runway indicates a runway constructed of portland-cement concrete, while asphalt runway indicates a runway surfaced with asphaltic concrete. A slag or limestome aggregate was used for both types of concrete.)

The type of metal, the bearing pressure on the metal, the slide speed, and the fuel were varied to simulate, within the limitations of the experimental apparatus, the conditions that might be encountered in an airplane crash on a paved runway. Five types of metal were studied: 2024-T3 aluminum alloy, Ti-100A titanium alloy, FS1 magnesium alloy, chrome-molybdenum (SAE 4130) steel, and AISI 347 stainless steel. 100/130-Octane aviation gasoline, JP-4 fuel, kerosene, and preheated SAE No. 5 lubricating oil were sprayed around the sample to provide the combustible atmosphere.

APPARATUS AND PROCEDURE

The drag apparatus (fig. 1) was constructed so that a bearing load could be applied to a metal sample and the sample could be pulled over a runway surface while surrounded by a combustible fuel-air mixture. A steel framework was attached by hinge pins to a pickup truck; and the metal sample, the weights, and the fuel spray system were attached to this framework. The details of the apparatus are illustrated in figures 2 and 3.

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The metal sample was lowered to, or raised from, the runway by a hoist on the truck and a cable attached to the framework. A platform on the framework held weights which, combined with the weight of the framework, placed a bearing load on the metal sample. The bearing pressure on the sample could be varied from a minimum of about 20 pounds per square inch to a maximum of 1455 pounds per square inch by changing the number of weights and the surface area of the metal sample. The sliding surfaces of the samples were varied from 3/4-inch-diameter to a 10- by 1-inch rectangle to obtain a large range of bearing pressures.

During a crash, fuel spilled from ruptured tanks into the airstream produces large clouds of fuel mist around the aircraft. Damaged sections of the lubrication system can also produce a cloud of oil vapor and mist around the nacelles (ref. 1). A combustible atmosphere similar to that which could be encountered in a crash was produced by a fuel spray system (fig. 4). The spray nozzles were located so as to surround the metal sample and the abraded particles with the combustible mist-air mixture. The fuel flow was adjusted to compensate for wind and slide speeds to provide a combustible atmosphere.

Baffles attached to the front and sides of the spray manifold protected against excessive fuel dilution by the air at slide speeds up to 40 miles per hour and in moderate wind. A spark plug suspended behind the sample was used to check the presence of a combustible fuel-air mixture. The spark plug was located directly adjacent to or anywhere up to 4 feet behind the sliding sample.

Before starting the friction-ignition experiments, the fuel flow necessary to obtain a combustible mixture at various speeds under the prevailing wind conditions was determined. The entire area up to 4 feet behind the sample was explored with a spark plug to be sure that there was a combustible mixture throughout. The presence of a combustible mixture in the fuel spray zone was checked before each day's experiments and after any change in wind velocity during the day.

After the fuel flow for obtaining a combustible mixture had been determined, each run was made as follows: The truck was accelerated to the desired speed as indicated by the truck speedometer. The spray system was turned on during the acceleration, and at the desired speed the metal sample was lowered to the runway. If ignition did not occur, the spark plug was energized near the end of the run and before the speed was reduced to be certain that a combustible mixture was present. The slide time until ignition occurred was measured with a stop watch.

This procedure was repeated with each metal for different slide speeds, bearing pressures, combustibles, and types of runway. Initial experiments were generally made at a moderate bearing pressure and a slide speed of 20 miles per hour. Additional experiments were then made at different bearing pressures and slide speeds to determine within the limitations of the experimental apparatus the lowest bearing pressures and slide speeds at which ignition would occur.

RESULTS AND DISCUSSION

The results of the study are presented individually for each of the metal studies. The conditions of the experiments with each metal on concrete and asphalt runways and with the different fuel sprays are sum- 4320
marized in table I.

Aluminum

2024-T3 Aluminum alloy sliding over either concrete or asphalt runways at speeds up to 40 miles per hour and bearing pressures up to 1455 pounds per square inch did not produce friction sparks that would ignite the combustible mixture. The complete range of speeds and bearing pressures was applied to the sample on a concrete runway with gasoline, JP-4 fuel, kerosene, or preheated SAE No. 5 oil providing the combustible fuel-air mixture. None of these combustibles was ignited. Aluminum samples were also dragged over an asphalt runway at slide speeds of 20 to 40 miles per hour with bearing pressures of 64 to 1455 pounds per square inch applied to the sample without igniting a JP-4 fuel mist.

The abraded aluminum left a smear of metal on the runway surface and sprayed aluminum dust behind the sample. At low bearing pressures, the aluminum sample was dragged up to 2600 feet, but at the high bearing pressures the slide distance was limited by the complete abrasion of the sample. Eight and one-half inches of 3/4-inch-diameter aluminum bar were abraded by sliding over a concrete runway for only 300 to 400 feet when a bearing pressure of 1455 pounds per square inch was applied to the sample.

The results of these experiments agree with the literature describing various modes of ignition of combustible vapor-air mixtures. Reference 3 indicates that small metal particles must be very hot to ignite combustible vapor-air mixtures. A sphere 0.25 inch in diameter must be heated to approximately 1800° F to ignite a combustible pentane-air mixture. The ignition temperature of pentane is about the same as that for gasoline.

Since the melting temperature of 2024-T3 aluminum alloy is 935° to 1180° F (ref. 4), globules of molten aluminum over 1/4 inch in diameter would be required to ignite the combustible vapor-air mixtures. Since it is very unlikely globules of molten aluminum as large as 1/4-inch diameter would be produced when aluminum is being abraded in this fashion, hot abraded aluminum particles are not considered to be a crash-fire ignition source.

There also was no indication that burning aluminum particles would be an ignition source. Normal grinding operations of aluminum do not produce luminous particles (ref. 2), and no luminous particles were observed in these runway experiments. Additional experiments were made to closely observe abraded aluminum particles. A sample of 2024-T3 aluminum bar stock was held against a rotating emery wheel. No luminous particles were observed in ordinary incandescent room light. However, in darkness, some very infrequent luminous particles were observed. These sparks were of very low intensity, were visible only directly adjacent to the sample, and remained luminous for a very brief time interval. These particles may have been small burning aluminum particles or particles abraded from the grinding wheel. Since these particles could be seen only in darkness, they are very small. Reference 3 indicates that even luminous particles large enough to be seen in daylight often do not have enough energy to ignite a combustible fuel-air mixture. Although sliding aluminum might occasionally produce burning particles, the particles are so small that they are not likely to be an ignition source.

In order to determine if the surface of the sliding parent aluminum or the hot metal smeared on the runway would be hot enough to ignite the combustible fuel-air mixture, an additional series of experiments were made. A sample with a bearing load applied was dragged over a concrete runway while fuel was sprayed around the sample and on the runway in front of the sample. At the end of the runway, the sample was abruptly stopped and for about 30 seconds fuel was sprayed intermittently to maintain a combustible atmosphere around the hot sample. No ignitions occurred with fuel sprays of gasoline, JP-4 fuel, or preheated SAE No. 5 oil.

Ignition of fuel on the hot surface of the sliding metal or on the hot metal smeared onto the runway is similar to the ignition of fuel on hot metal plates in open air. The ignition temperature of fuels on hot metal plates in open air where there is active convection is much higher than in heated enclosures, which confine a small quantity of combustible mixture in a high-temperature region. Inspection of the metal smeared on the runway showed that it was near or at its melting temperature when abraded. Therefore, the maximum expected temperature of the abraded metal and the surface of the sample would be within the melting range of 2024-T3 aluminum alloy, which is 935° to 1180° F (ref. 4). Reference 3 indicates that the ignition temperature of the fuels studied on aluminum plates in open air would be slightly above the melting range of 2024-T3 aluminum alloy. These ignition temperatures are for quiescent mixtures, and quiescent conditions are extremely unlikely in a crash. Therefore, the metal temperatures required to ignite the fuel in a crash would be higher than the temperature of the sample or of the metal smeared onto the runway. It can be concluded then that neither the surface of the aluminum sample nor the aluminum smeared onto the runway is hot enough to act as an ignition source of combustible fuel-air mixtures.

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On the basis of these experiments and the literature study, it is believed aluminum would not be a crash-fire ignition source even though the sliding speed and bearing pressure were greater in a crash than those used in this study.

Titanium

Ti-100A Titanium alloy sliding over both concrete and asphalt runways produced sparks that ignited the combustible mist in all experiments. The conditions at which ignition occurred with minimum bearing pressure, with minimum slide speed, or with minimum slide time are summarized for titanium in table II. In these experiments the minimum bearing pressures applied to the sample were from 21 to 23 pounds per square inch and the minimum slide speeds were less than 5 miles per hour. At slide speeds of 10 miles per hour and above, the fuel mist was ignited as soon as the sample was lowered to the runway. At slower speeds the sample had to be dragged up to 330 feet before ignition occurred. In all the experiments the fuel mist was ignited as soon as sparks were observed. 4320

Very large quantities of large bright sparks (fig. 5) could be seen when the metal slid on the runway at speeds of 10 miles per hour and above without fuel being sprayed. At slide speeds below 10 miles per hour, only occasional sparks were produced. The bright sparks seen in this study indicate that the abraded particles are burning and have considerable thermal energy.

The ease with which titanium sparks are produced and the fact that they ignited gasoline, kerosene, JP-4 fuel, and preheated SAE No. 5 lubricating oil indicate that they are a very probable ignition source of a crash fire if combustible fuel-air mixtures occur in the crash in the spark zone.

Magnesium

Friction sparks produced by FS1 magnesium alloy sliding over a concrete runway ignited both gasoline and JP-4 fuel mists. Gasoline and JP-4 fuel were the only combustibles used in this study. The minimum conditions at which ignition occurred are summarized in table III. At bearing pressures of 37 pounds per square inch and above, ignition occurred in all the experiments. At bearing pressures of 18 to 30 pounds per square inch, ignition occurred in four of twelve trials using gasoline and in three of five trials using JP-4 fuel. In only one experiment, at a bearing pressure of 54 pounds per square inch and a slide speed of 30 miles per hour, was the fuel mist ignited as soon as the sample was lowered to the runway surface. In all the other experiments, it was necessary to drag the magnesium over the runway for a short distance before ignition occurred.

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The sliding magnesium left traces of the metal on the runway and deposited a residue of magnesium powder on the rear of the fuel spray manifold. Large bright flashes of burning magnesium powder (fig. 6) were produced behind the sample when it was dragged without fuel being sprayed. These flashes occurred intermittently, and their frequency and size increased as the slide distance increased.

No individual glowing particles were observed in these experiments. Normal magnesium grinding operations do not produce luminous particles (ref. 2). Although the velocities involved in grinding are greater than the slide speed in these runway experiments, the bearing pressures and rate of metal abrasion were greater in the runway experiments than in the grinding operations. The greater bearing pressure and accompanying increased abrasion are apparently responsible for the added energy that ignites the abraded magnesium powder.

Since magnesium is a relatively soft metal, little mechanical energy is required to tear the particles from the parent metal. However, since the metal particles ignite at a relatively low temperature, 970° to 1005° F (ref. 5), not much energy is required for ignition and the powdered metal ignites easily. Once ignited, the burning powder becomes a powerful ignition source. The theoretical flame temperature of pure magnesium is 8760° F (ref. 6). The actual flame temperature of this alloy will be lower but still quite hot. The ease with which magnesium particles burn, the high flame temperatures, and the size of the burning magnesium flashes indicate that magnesium aircraft parts will produce friction sparks on sliding contact with the runway that can easily start a crash fire.

Chrome-Molybdenum Steel

Friction sparks produced by chrome-molybdenum (SAE 4130) steel sliding over both concrete and asphalt runways ignited all the combustibles studied. The minimum conditions at which ignition occurred are shown in table IV.

Gasoline, JP-4 fuel, kerosene, and preheated SAE No. 5 oil mists were ignited by steel sliding over a concrete runway at bearing pressures as low as 19 to 32 pounds per square inch and slide speeds as low as 10 and 20 miles per hour. However, ignitions of the kerosene mist (table V) occurred in only 22 of the 38 trials throughout the range of bearing pressures and slide speeds used.

In no experiments did ignition occur as soon as the sample was lowered to the runway. A few ignitions occurred after 2 to 3 seconds of sliding on a concrete runway, but in the majority of the experiments the sample slid for a much longer time interval. Immediately after initial contact of the steel sample with the runway, only a few small sparks were observed. The number and intensity of the sparks increased as the sample slid and appeared to reach a maximum after a short distance.

On an asphalt runway, sparks from the steel occasionally ignited the JP-4 fuel spray at bearing pressures of 108 to 816 pounds per square inch and slide speeds of 10 to 40 miles per hour, as shown in table VI. In some of these experiments, the ignitions occurred 10 to 15 feet behind the sample and did not propagate throughout the fuel mist. 4320

On an asphalt runway, the minimum slide time before ignition occurred was 10 seconds (table VI). The slide distance, before a maximum quantity of sparks was produced, was longer on an asphalt runway than on a concrete one.

The size and temperature of the particles abraded on the asphalt runway are apparently of marginal thermal energy for igniting the fuel mist. The ignitions which occurred 10 to 15 feet behind the sample may be the result of a longer residence time of the abraded particle with the fuel. In these experiments, an assured combustible atmosphere is present only 4 feet behind the sample and will not occur consistently 10 to 15 feet behind the sample. The infrequent ignitions 10 to 15 feet behind the sample may be due to the inconsistent presence of a combustible mixture and the marginal size and temperature of the abraded particles. In an actual crash, there may be a larger zone of a combustible atmosphere which might increase the probability of ignition when steel is sliding over an asphalt runway.

Stainless Steel

Friction sparks produced by AISI 347 stainless steel sliding over a concrete runway ignited mists of gasoline, JP-4 fuel, and kerosene. The minimum conditions at which ignition occurred are summarized in table VII. At bearing pressures below 50 pounds per square inch, ignitions occurred in only about one-fifth of the experiments. At higher bearing pressures, ignitions occurred in about one-half of the experiments at slide speeds of 20 miles per hour but in all the experiments at 30 miles per hour.

Fewer sparks appeared to be produced by the sliding of stainless steel than by the sliding of chrome-molybdenum (SAE 4130) steel. In most of the experiments, the sample had to slide a relatively long distance before ignition occurred.

These experiments indicate that the friction sparks from stainless steel are also a potential ignition source of an aircraft crash fire.

CONCLUDING REMARKS

As a result of this study, it is apparent that aluminum is the safest metal with respect to friction sparks since it produced no visible sparks and did not ignite combustible mists even at the maximum obtainable bearing pressures (1455 psi) and slide speeds (40 mph). Although aluminum will not produce hazardous friction sparks, the thin aluminum skin on an aircraft may be torn in a crash or be abraded by sliding and thereby expose more hazardous metals. In an ordinary belly landing, however, an aluminum fuselage skin would be worn through only in localized spots when sliding on a runway because the weight of the aircraft is distributed over a relatively large area and the unit bearing pressure is low. Thus, the possibility of exposing more hazardous metals is small under these circumstances.

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Of all the metals studied, titanium ignited the fuel mists most readily; but magnesium, chrome-molybdenum steel, and stainless steel all ignited the fuel mists at slide speeds and bearing pressures less than those to be expected in an airplane crash. Therefore, any of these metals sliding over a runway can be a crash-fire ignition source.

Although titanium produced hazardous friction sparks on an asphalt runway as readily as on a concrete runway, chrome-molybdenum steel did not. However, the chrome-molybdenum steel sliding on an asphalt runway ignited the fuel spray at moderate speeds and bearing pressures. It is believed that magnesium and stainless steel sliding on an asphalt runway would produce sparks under approximately the same conditions as did chrome-molybdenum steel. The probability of a metal producing hazardous sparks on an asphalt runway having an aggregate of hard rocks, such as quartz or flint, would be greater than on the asphalt runways used, which had an aggregate of slag or limestone. Although an asphalt runway is slightly safer with respect to friction sparks from some metals, some fuel when spilled may dissolve the asphalt; and, if an ignition did occur, the asphalt would add fuel to the fire.

Titanium briefly striking another hard surface, such as a stone or other piece of metal, will probably produce hazardous friction sparks; but magnesium, chrome-molybdenum steel, and stainless steel are less likely to. In these studies titanium instantly ignited the fuel mists at low slide speeds and bearing pressures. However, magnesium, chrome-molybdenum steel, and stainless steel usually had to be preheated by being dragged over the runway for a short distance before they produced sparks that would ignite the fuel mists. Since the metal would not be preheated in a brief contact, magnesium, chrome-molybdenum steel, and stainless steel are less likely to produce hazardous sparks by striking isolated stones or other hard surfaces if an emergency landing is made on an earthen surface.

Fuels of low volatility may be slightly safer with respect to friction-spark ignitions than fuels of high volatility. The fuel mists must be vaporized and then raised to their ignition temperatures before they burn. Gasoline-type fuels, being highly volatile, will readily vaporize at ambient temperatures, while the heat for vaporizing low-volatile kerosene-type fuels must come partly from the ignition source. However, the ignition temperature of kerosene-type fuels is lower than that of gasoline. These two effects thus tend to cancel each other, and the net effect of decreasing the volatility is not as great as expected. The extent of this benefit with respect to friction sparks is indicated by comparing the ease with which sparks from chrome-molybdenum steel ignited gasoline and kerosene.

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Although the kerosene mist was ignited at nearly as low bearing pressures and slide speeds as was the gasoline mist, the ignitions of kerosene occurred inconsistently throughout the range of the experiments. The thermal energy of the friction sparks from chrome-molybdenum steel are apparently of marginal thermal energy to both vaporize and ignite the kerosene mist. However, sparks of large thermal energy, such as from titanium, will ignite mists of low-volatile fuels as easily as high-volatile fuels.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, February 27, 1957

REFERENCES

1. Pinkel, I. Irving, Preston, G. Merritt, and Pesman, Gerard J.: Mechanism of Start and Development of Aircraft Crash Fires. NACA Rep. 1133, 1952. (Supersedes NACA RM E52F06.)

2. Outwater, J. O., and Shaw, M. C.: Surface Temperatures in Grinding. Trans. ASME, vol. 74, no. 1, Jan. 1952, pp. 73-86; discussion, pp. 81-86.

3. Scull, Wilfred E.: Relation Between Inflammables and Ignition Sources in Aircraft Environments. NACA Rep. 1019, 1951. (Supersedes NACA TN 2227.)

4. Anon.: Alcoa Aluminum and Its Alloys. Aluminum Co. Am., Pittsburgh (Pa.), 1947.

5. Hartmann, Irving, Nagy, John, and Brown, Hylton R.: Inflammability and Explosibility of Metal Powders. R.I. 3722, Bur. Mines, Oct. 1943.

6. Anon.: Magnesium Alloys and Products. Magnesium Div., The Dow Chem. Co., 1950.

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TABLE I. - SUMMARY OF EXPERIMENTAL CONDITIONS

Metal	Runway	Fuel spray	Number of trials	Number of ignitions	Bearing pressures, psi	Slide speeds, mph	Maximum slide distance, ft
2024-T3 Aluminum alloy	Concrete	Gasoline	30	None	52 to 1455	10 to 40	2600
	Concrete	JP-4 Fuel	14	None	63 to 1455	10 to 40	2200
	Concrete	Kerosene	12	None	64 and 1455	20 to 40	1850
	Concrete	SAE No. 5 lubricating oil	15	None	64 to 1455	20 to 40	2060
	Asphalt	JP-4 Fuel	18	None	64 to 1455	20 to 40	1350
Ti-100A Titanium alloy	Concrete	Gasoline	20	20	21 to 143	<5 to 40	105
	Concrete	JP-4 Fuel	6	6	21 to 24	<5 to 20	320
	Concrete	Kerosene	6	6	23 to 26	<5 to 20	330
	Concrete	SAE No. 5 lubricating oil	7	7	21	5 to 20	15
	Asphalt	JP-4 Fuel	8	8	21 to 34	<5 to 20	160
FS1 Magnesium alloy	Concrete	Gasoline	15	15	37 to 81	10 to 40	1700
	Concrete	Gasoline	12	4	20 to 30	10 to 40	2750
	Concrete	JP-4 Fuel	4	4	37 to 57	10 and 20	540
	Concrete	JP-4 Fuel	5	3	18 to 25	10 and 20	1500
Chrome-molybdenum (SAE 4130) steel	Concrete	Gasoline	12	12	20 to 1280	10 to 40	1000
	Concrete	Gasoline	2	0	17	10	1100
	Concrete	JP-4 Fuel	19	19	19 to 816	10 to 40	1050
	Concrete	Kerosene	38	[a]22	23 to 414	20 to 35	2060
	Concrete	SAE No. 5 lubricating oil	7	7	32 to 64	20 and 30	1450
	Asphalt	JP-4 Fuel	62	[b]20	44 to 816	10 to 40	1850
AISI 347 Stainless steel	Concrete	Gasoline	3	2	66 to 77	20	1790
	Concrete	Gasoline	4	4	50	30	1100
	Concrete	Gasoline	5	1	50	20	1820
	Concrete	Gasoline	13	2	23 to 34	20 and 30	2060
	Concrete	JP-4 Fuel	3	3	66	20 and 30	1320
	Concrete	JP-4 Fuel	3	3	50	30	920
	Concrete	JP-4 Fuel	3	1	50	20	1440
	Concrete	JP-4 Fuel	5	1	34	20 and 30	1640
	Concrete	Kerosene	7	5	50	20 and 30	1700
	Concrete	Kerosene	6	2	34	20 and 30	1640

[a]Inconsistent ignitions, see table VI.

[b]Inconsistent ignitions, see table VII.

TABLE II. - MINIMUM CONDITIONS AT WHICH IGNITION OCCURRED WITH Ti-100A TITANIUM ALLOY

Runway	Fuel spray	Lowest slide speed and shortest slide time at which ignition occurred with minimum bearing pressure used			Lowest bearing pressure and shortest slide time at which ignition occurred with minimum slide speed used			Lowest bearing pressure and slowest slide speed at which ignition occurred at shortest slide time		
		Speed, mph	Time, sec	Pressure, psi	Pressure, psi	Time, sec	Speed, mph	Pressure, psi	Speed, mph	Time, sec
Concrete	100/130-Octane gasoline	10	Instantaneous	21	38	6	<5	21 38	10 5	Instantaneous Instantaneous
	JP-4 Fuel	<5 5	71 Instantaneous	21 21	21	71	<5	21	5	Instantaneous
	Kerosene	<5	6	23	23	6	<5	26	5	Instantaneous
	Preheated SAE No. 5 oil	5	Instantaneous	21	21	Instantaneous	5	21	5	Instantaneous
Asphalt	JP-4 Fuel	10	Instantaneous	21	24	35	<5	21 26	10 5	Instantaneous Instantaneous

TABLE III. - MINIMUM CONDITIONS AT WHICH IGNITION OCCURRED WITH FS1 MAGNESIUM ALLOY

Runway	Fuel spray	Lowest slide speed and shortest slide time at which ignition occurred with minimum bearing pressure used			Lowest bearing pressure and shortest slide time at which ignition occurred with minimum slide speed used			Lowest bearing pressure and slowest slide speed at which ignition occurred at shortest slide time		
		Speed, mph	Time, sec	Pressure, psi	Pressure, psi	Time, sec	Speed, mph	Pressure, psi	Speed, mph	Time, sec
Concrete	100/130-Octane gasoline	20	5	19	37	5	10	54	30	Instantaneous
	JP-4 Fuel	20	51	18	37	7	10	37	10	7

TABLE IV. - MINIMUM CONDITIONS AT WHICH IGNITION OCCURRED WITH CHROME-MOLYBDENUM (SAE 4130) STEEL

Runway	Fuel spray	Lowest slide speed and shortest slide time at which ignition occurred with minimum bearing pressure used			Lowest bearing pressure and shortest slide time at which ignition occurred with minimum slide speed used			Lowest bearing pressure and slowest slide speed at which ignition occurred at shortest slide time		
		Speed, mph	Time, sec	Pressure, psi	Pressure, psi	Time, sec	Speed, mph	Pressure, psi	Speed, mph	Time, sec
Concrete	100/130-Octane gasoline	20	12	[a]20	145	15	10	145	20	8
	JP-4 Fuel	10	73	19	19 145	73 23	10 10	24	20	2
	Kerosene[b]	20	29	23	23 280	29 4	20 20	280	30	2
	Preheated SAE No. 5 oil	20	11	32	32 64	11 7	20 20	64	20	7
Asphalt	JP-4 Fuel[b]	20	20	[a]108	680 [c]816	15 10	10 10	548 [c]816	30 10	10 10

[a]Not lowest used but lowest that resulted in ignition.

[b]Inconsistent ignitions, see tables V and VI.

[c]Ignition 10 to 15 ft behind sample, see table VI.

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TABLE V. - FRICTION-SPARK IGNITION EXPERIMENTS WITH CHROME-MOLYBDENUM (SAE 4130) STEEL ON CONCRETE RUNWAY WITH KEROSENE FUEL SPRAY

Bearing pressure, psi	Slide speed, mph	Ignition	Slide time, sec	Approximate slide distance, ft
23	20	No	32	940
23	20	Yes	29	850
23	30	Yes	6	260
24	30	Yes	27	1190
24	30	Yes	16	700
24	30	No	30	1320
25	20	No	55	1610
27	20	No	55	1610
28	20	No	46	1350
30	20	Yes	12	350
30	20	Yes	19	560
32	20	Yes	6	170
46	20	Yes	43	1260
54	20	No	70	2060
54	30	Yes	18	790
64	20	Yes	23	680
64	20	No	57	1670
65	30	Yes	12	530
145	20	No	65	1910
145	20	Yes	37	1090
145	20	No	54	1580
145	20	Yes	16	470
145	30	No	42	1850
145	30	No	39	1720
145	30	Yes	13	570
280	20	No	56	1640
280	20	No	47	1380
280	20	Yes	4	120
280	20	Yes	4	120
280	25	Yes	3	110
280	30	No	23	1010
280	30	Yes	2	90
280	35	No	40	2050
414	20	No	57	1670
414	20	Yes	7	210
414	20	Yes	14	410
414	30	Yes	25	1100
414	30	Yes	6	260

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TABLE VI. - FRICTION-SPARK IGNITION EXPERIMENTS WITH CHROME-MOLYBDENUM (SAE 4130) STEEL ON ASPHALT RUNWAY WITH JP-4 FUEL SPRAY

Bearing pressure, psi	Slide speed, mph	Ignition	Slide time, sec	Approximate slide distance, ft
44	20	No	32	940
45	20	No	58	1700
46	20	No	45	1320
49	30	No	38	1670
50	30	No	39	1710
52	30	No	32	1410
55	30	No	37	1620
59	20	No	61	1790
63	20	No	63	1850
70	20	No	20	590
70	30	No	13	570
108	20	Yes	20	590
145	20	No	46	1350
145	20	Yes	12	350
145	20	No	51	1500
145	20	No	54	1580
145	30	No	37	1620
145	30	Yes[a]	12	530
145	30	Yes[a]	13	570
145	30	Yes[a]	24,28	1050,1230
145	40	No	22	1290
145	40	No	21	1230
145	40	No	24	1410
150	20	Yes[a]	24	710
180	20	Yes[a]	14,24	410,710
280	20	No	27	790
280	20	Yes	31	910
280	20	No	42	1230
280	25	No	34	1240
280	30	No	39	1710
280	30	No	37	1630
280	30	No	39	1710
280	30	No	19	840
414	20	No	30	880
414	20	No	25	730
414	30	No	18	790

[a]Brief fire or fires 10 to 15 ft behind sample.

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TABLE VI. - Concluded. FRICTION-SPARK IGNITION EXPERIMENTS WITH CHROME-MOLYBDENUM (SAE 4130) STEEL ON ASPHALT RUNWAY WITH JP-4 FUEL SPRAY

Bearing pressure, psi	Slide speed, mph	Ignition	Slide time, sec	Approximate slide distance, ft
414	30	No	20	880
548	20	Yes[a]	24	700
548	20	Yes	36	1060
548	30	Yes	10	440
680	10	Yes	15	220
680	20	No	26	760
680	20	No	26	760
680	20	Yes[a]	15	440
680	20	No	26	760
680	30	No	26	1140
816	10	Yes[a]	10	150
816	20	No	35	1030
816	20	Yes[a]	30	880
816	20	No	29	850
816	20	Yes	28	820
816	20	Yes	33	970
816	20	No	43	1260
816	20	Yes	35	1030
816	30	No	40	1760
816	30	No	33	1450
816	30	No	38	1670
816	30	Yes[a]	11	480
816	30	Yes	10	440
816	40	No	31	1820
816	40	No	26	1530
816	40	No	27	1590

[a]Brief fire or fires 10 to 15 ft behind sample.

TABLE VII. - MINIMUM CONDITIONS AT WHICH IGNITION OCCURRED WITH AISI 347 STAINLESS STEEL

Runway	Fuel spray	Lowest slide speed and shortest slide time at which ignition occurred with minimum bearing pressure used			Lowest bearing pressure and shortest slide time at which ignition occurred with minimum slide speed used			Lowest bearing pressure and slowest slide speed at which ignition occurred at shortest slide time		
		Speed, mph	Time, sec	Pressure, psi	Pressure, psi	Time, sec	Speed, mph	Pressure, psi	Speed, mph	Time, sec
Concrete	100/130-Octane gasoline	20	54	[a]27	27 77	54 7	20 20	77	20	7
	JP-4 Fuel	30	26	34	50	42	20	50	30	3
	Kerosene	20	15	34	34 50	15 5	20 20	50	20	5

[a]Not lowest used but lowest that resulted in ignition.

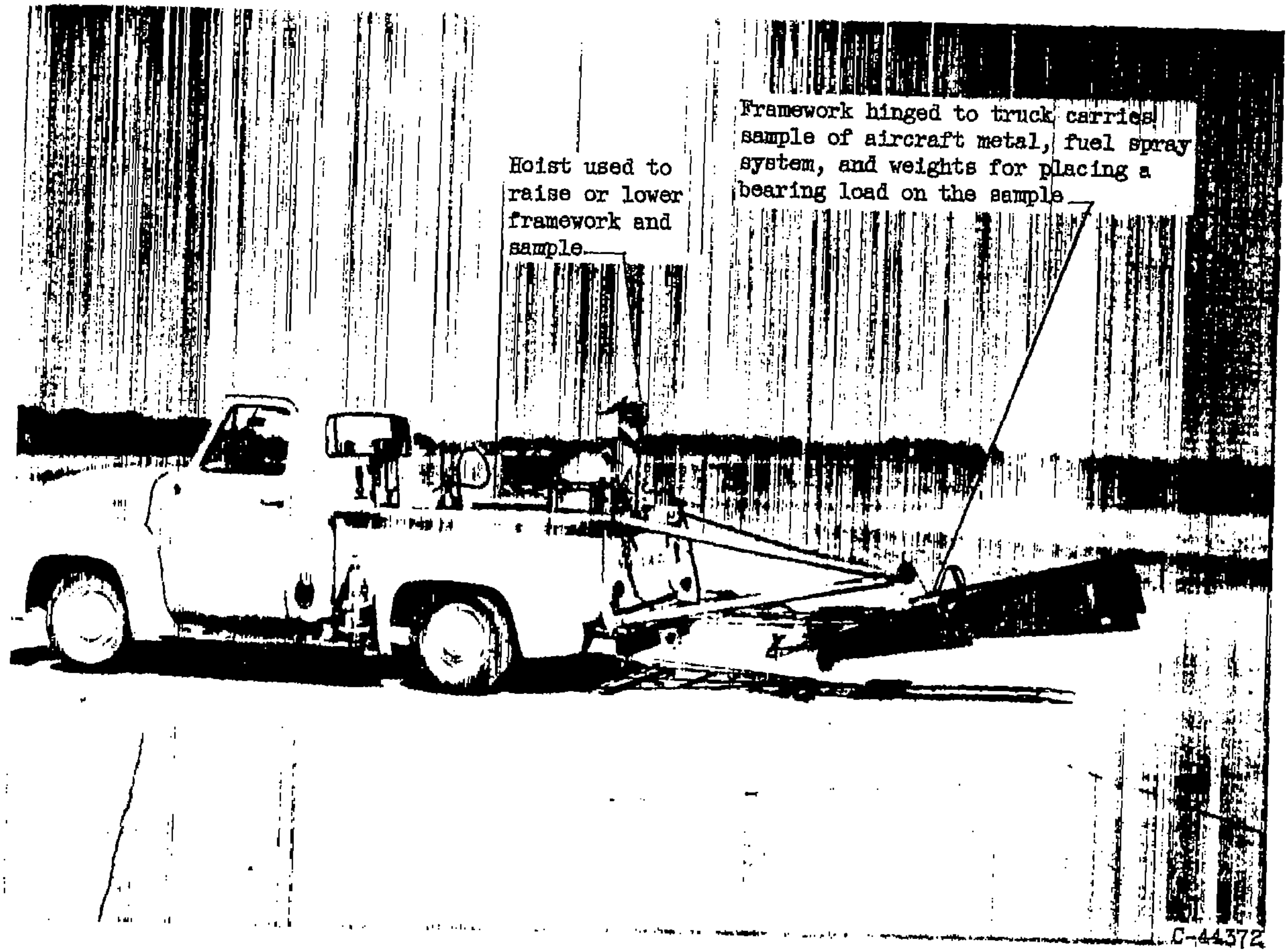

Figure 1. - Experimental apparatus.

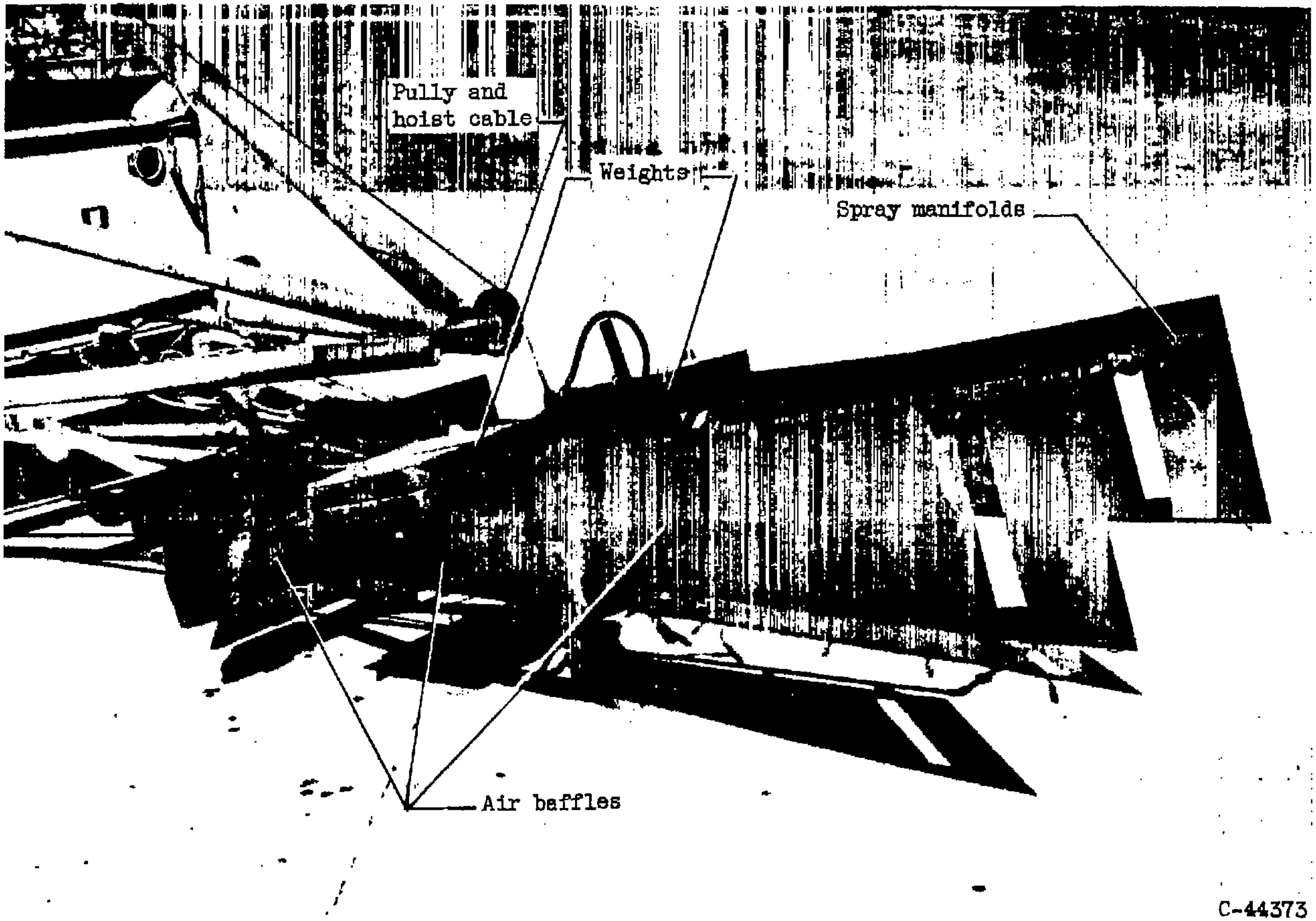

Figure 2. - Framework holding weights, fuel spray system, and air baffles.

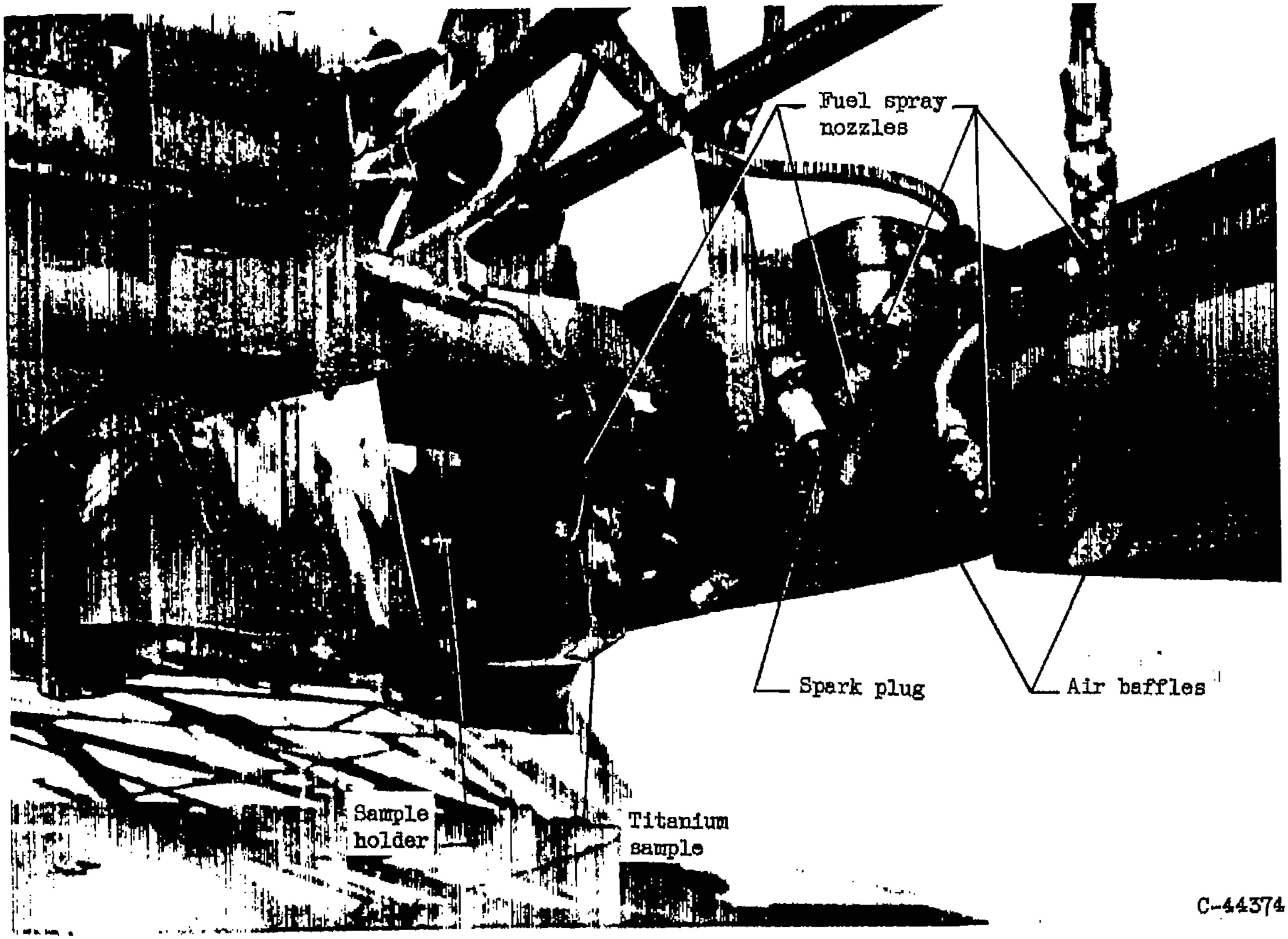

Figure 3. - Metal sample held in holder and surrounded by fuel spray nozzles. One air baffle has been removed.

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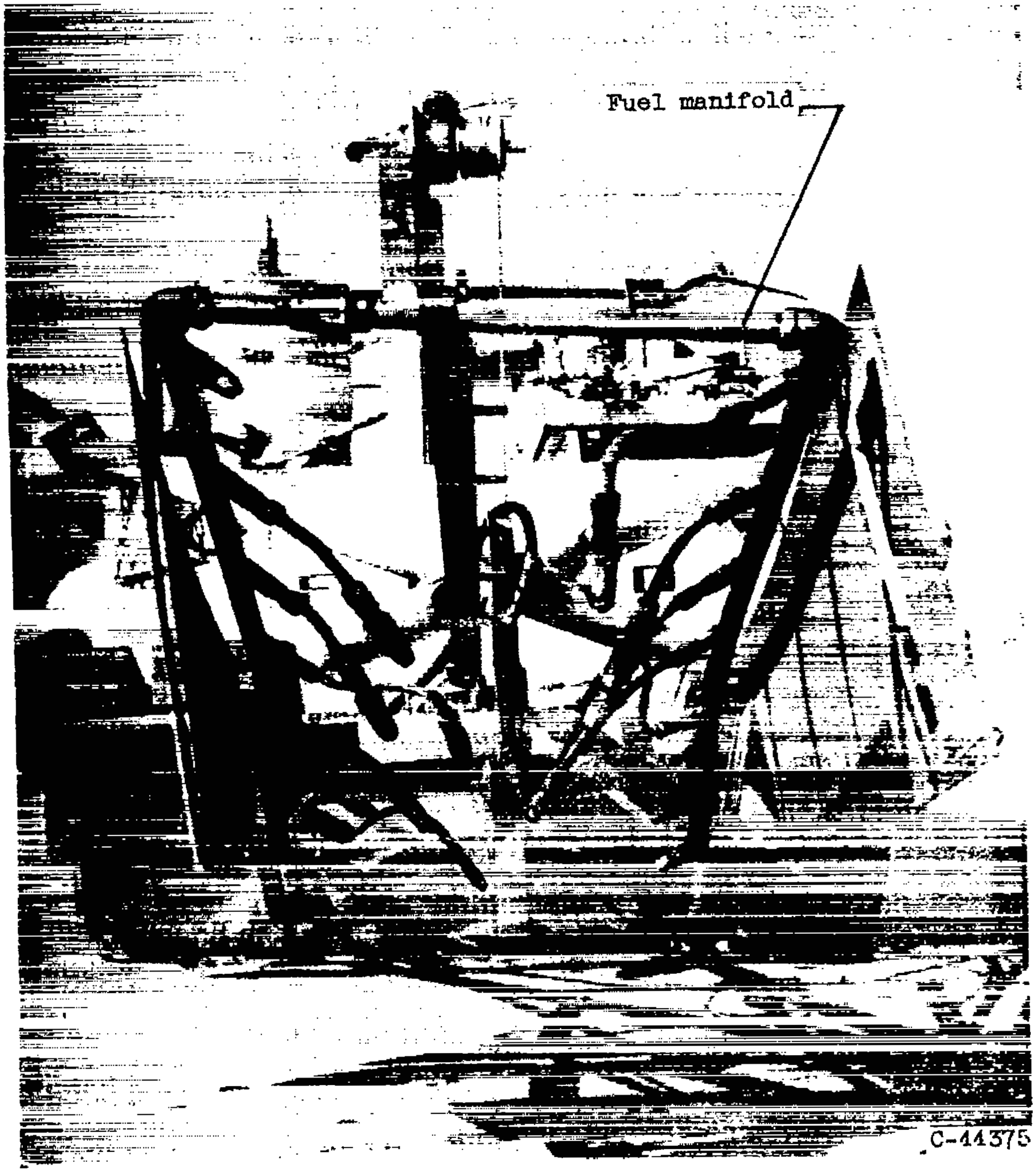

Figure 4. - Fuel spray system.

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Figure 5. - Friction sparks produced by titanium sample sliding at 30 miles per hour with load of 55 pounds per square inch. No fuel is being sprayed.

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Figure 6. - Burning magnesium powder produced by sample sliding at 20 miles per hour with load of 70 pounds per square inch. No fuel is being sprayed.

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APPRAISAL OF THE HAZARDS OF FRICTION-SPARK IGNITION

OF AIRCRAFT CRASH FIRES

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